AD-A247 139

PAGE

Form Approved
OMB No. 0704-0188

Public reporting b... gathering and ma... collection of infor... Davis Highway, Su... ur per response, including the time for reviewing instructions, searching existing data sources, ...on of information. Send comments regarding this burden estimate or any other aspect of this ...n Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson ...t and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
12-6-91

3. REPORT TYPE AND DATES COVERED
Final Technical Report (5/1/89-9/30/91)

4. TITLE AND SUBTITLE Proposal for a Workshop in the Physics and Application of Hollow Electrode Glow Switches (U)

5. FUNDING NUMBERS
61102F
2301/A7

6. AUTHOR(S)
Martin Gundersen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Southern California
Dept. of Electrical Engineering-Electrophysics

8. PERFORMING ORGANIZATION REPORT NUMBER
AFOSR-TR- 92 0149

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Lt. Col. James Lupo
Air Force Office of Scientific Research
Building 410
Bolling Air Force Base, DC 20332-6448

NE

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFOSR-89-0342

11. SUPPLEMENTARY NOTES

DTIC
ELECTE
MAR 0 6 1992
S D D

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release: Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The purpose of the 1989 NATO ARW was to develop applications for and an improved understanding of the physics for high current emission and conduction observed in hollow cathode-hollow anode switches including the pseudospark and back-lighted thyratron (BLT). New applications include highly emissive cathodes for microwave devices, accelerators and free electron lasers, high power tubes, electron and ion beams, microlithography, accelerators, and other plasma devices. Recent research has produced this new generation of gas-phase plasma switches that are characterized by very high current emission and conduction while operating in a glow mode. The cathode properties are especially remarkable - about 2 orders of magnitude larger emission than existing thermionic cathodes. Part of the meeting was devoted to understanding these properties, and exploiting applications of this cathode. These results deserve study in order to understand the underlying physical mechanisms, and to develop ideas and insight into future applications, and foster coherent research in this area. This meeting was also motivated by the fact that there are many new applications of these devices under consideration. These include new types of ion and electron beams for microelectronic technology, accelerators, other plasma loaded devices, plasma lenses for high energy physics, plasma accelerators, applications requiring very high cathode emission such as cathodes for pulsed accelerators and microwave sources. The report and the Proceedings summarize results of a meeting between physicists, engineers, and applied scientists considering further developments in physics and engineering and industrial applications.

14. SUBJECT TERMS
Pseudospark, Back-Lighted Thyratron (BLT), free electro lasers, high energy physics, plasma lenses, plasma accelerators, high cathode emission, gas-phase plasma cathode properties

15. NUMBER OF PAGES
22

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

FINAL TECHNICAL REPORT

Application Process:

The NATO ARW application process and format is an important mechanism for preparing and conducting a technical meeting in areas of emerging importance. The ARW is regarded by the technical community as supporting the emergence of the technical subject matter. The focus provided by the meeting has the benefit that is intended -- key people are attracted by the ARW, and a meeting that might not otherwise be possible is conducted at an especially important time.

In the general area of research involving applied physics topics it is somewhat more common to see meetings under NATO sponsorship using the ASI format. It was our experience that the one week format of the ARW was much more useful from the point of view of impacting the research area and encouraging the participation of the best people. This conclusion was generally supported by comments from the participants. Based on these comments I would strongly encourage the use of the ARW format for technical meetings that may be expected to have maximum impact on the advancement of technology.

Planning and Execution:

Planning for the ARW was considerably assisted by the cooperation of the technical committee, and especially the contributions of Prof. Gerhard Schaefer (Polytechnic U., NY, USA) and Dr. Klaus Frank (U. of Erlangen, West Germany). In addition, the Air Force Office of Scientific Research (Physics Division, Lt. Col. Bruce Smith) provided significant additional funding. There was very good cooperation from the participants, as evidenced by the fact that we have already collected almost all of the manuscripts for the publication of the Proceedings.

Execution was assisted by the Lillehammer hotel. The location was ideal. The staff was cooperative and the hotel was professional, courteous, and reliable. The only drawback was the rather continuous influx of tour buses. I would certainly recommend the hotel for NATO meetings.

A couple of letters are attached that are representative of the types of comments that we have received about the meeting.

Scientific Content of ARW

The purpose of the meeting was to investigate the physics and develop theoretical models for high current emission and conduction observed in hollow cathode-hollow anode switches, and use these models to discern applications. Recent research has produced a new generation of gas-phase plasma switches that are characterized by very high current emission and conduction while operating in a glow mode. These switches include the pseudospark and the BLT, both of which have hollow electrodes, switch over 10 to 100 kA peak current, and have cathodes with emission ≥ 10,000 A/cm^2 over ≥ 1 cm^2 area. The remarkable properties of these switches are very surprising in the light of considerable previous work in this area, and these results deserve study in order to understand the underlying physical mechanisms, and to develop ideas and insight into future applications, and foster coherent research in this area. This understanding is needed to determine the basic physical processes involved, and will form the basis for the design and optimization of these devices. This is important because there are many new applications of these devices, including highly emissive cathodes for microwave devices, accelerators and free electron lasers, high power tubes, electron and ion beams, microlithography, accelerators, and other plasma devices.

Advanced experimental and theoretical methods are now available to study these problems. These include laser induced fluorescence spectroscopy, highly time-resolved spectroscopic studies, surface studies, and sophisticated plasma simulation methods such as Monte-Carlo simulations and quantitative studies of microscopic processes in the bulk plasma and at the plasma-electrode interface. In addition, there are pressing engineering applications in the areas of lasers, particle beams, and high energy physics, where these principles should have significant impact. The meeting brought together these different disciplines.

An important result involved the cathode emission process. The cathode properties are especially remarkable - about 2 orders of magnitude larger emission than existing thermionic cathodes. There are many new applications of these devices under consideration. These include new types of ion and electron beams for microelectronic technology, accelerators, other plasma loaded devices, plasma lenses for high energy physics, plasma accelerators, applications requiring very high cathode emission such as cathodes for pulsed accelerators and microwave sources. As a direct result of the discussion among experts at the workshop, the relative role of the hollow cathode effect in the emission and so-called superemission process was determined.

The meeting at this time between physicists, engineers, and applied scientists provided a very timely, valuable and needed foundation for further developments in both physics and engineering and industrial applications.

The papers presented at the Conference were published in the book titled "Physics and Applications of Pseudosparks," Ed. by Martin A. Gundersen and Gerhard Schaefer (NATO ASI Series B: Physics Vol. 219). The book was published by Plenum Publishing Corp., New York, NY.

KEY SPEAKERS AND OTHER PARTICIPANTS AT THE NATO ADVANCED RESEARCH WORKSHOP

THE PHYSICS AND APPLICATIONS OF HIGH POWER HOLLOW ELECTRODE GLOW SWITCHES

July 17-21, 1989
Lillehammer, Norway

Key Speakers:

Prof. Peter Choi
Imperial College
Physics Dept., Blackett Lab.
London SW7 2BZ
United Kingdom

Prof. J. Christiansen
University of Erlangen
Erwin Rommel - Str. 1
8520 Erlangen
West Germany

Dr. K. Frank
Univ. of Erlangen
Erwin-Rommel-Str. 1
D-8520 Erlangen
West Germany

Dr. M.A. Gundersen
Dept. of Electrical Engr.
Univ. of Southern California
Los Angeles, CA 90089-0484
USA

Dr. W. Hartmann
University of Erlangen
Erwin Rommel - Str. 1
8520 Erlangen
West Germany

Prof. M. Kushner
Dept. of Electrical Engr.
Univ. of Illinois
Champaign, IL 61820
USA

Dr. J.E. Lawler
Dept. of Physics
Univ. of Wisconsin
Madison, WI 53706
USA

Dr. K. Mittag
Institut für Kernphysik II
Postfach 36 40
D -7500 Karlsruhe 1
F.R.G.

Dr. H. Riege
CERN Division PS
CH-1211
Geneve 23
Switzerland

Dr. G. Schaefer
Dept. of Electrical Engr.
Polytechnic University
Farmingdale, NY 11735
USA

Participants:

Prof. J. Almeida
Univ. of Minho
Largo de Paco
4719 Braga, Codex
Portugal

Mr. H. Bauer
Univ. of Southern California
Dept. of EE-EP
Los Angeles, CA 90089-0484
USA

Jack Bernardes
Naval Surface Warfare Cntr.
Code F 12
Dahlgren, VA 22448
USA

Dr. J-Pierre Boeuf
CNRS-U. P. Sabatier C.P.A.T.
118 Rt. de Narbonne
Toulouse 31062
France

Prof. Dr. W. Böttcher
Universitaet Hannover
Callin-Str. 38-D-3000
Hanover 1
Fed. Rep. of Germany

Prof. A.J. Davies
Univ. College of Swansea
Dept. of Physics
Swansea SA 28 PP
Wales, United Kingdom

Dr. F. M. Dias
Centro de Electrodinamica da
Univ. Technica de Lisboa
1096 Lisboa Codex
Portugal

Dr. I. Gallimberti
Univ. Degli
Univ. of Padova
35100 Padova
Italy

Dr. D. Karabourniotis
Univ. of Crete
Physics Department
Greece

Dr. Yitzhak Kaufman
Imperial College
Physics Dept., Blackett Lab.
London SW7 2BZ
United Kingdom

Mr. G. Kirkman
Dept. of EE-EP
Univ. of Southern California
Los Angeles, CA 90089-0484
USA

Dr. E. E. Kunhardt
Dept. of Electrical Engr.
Polytechnic University
Farmingdale, NY 11735
USA

Dr. Günter Lins
Siemens AG
P.O. Box 3220
D-8520 Erlangen
Fed. Rep. of Germany

Mr. L. Luessen
Naval Surface Warfare Cntr.
Code F 12
Dahlgren, VA 22448
USA

Dr. N. Marcuvitz
Dept. of Electrical Engr.
Polytechnic University
Farmingdale, NY 11735
USA

Mr. H. Menown
English Electric Valve Co.
Waterhouse Lane
Chelmsford, Essex CM 12 QU
United Kingdom

Dr. M. Mentzoni
Fysik Institute Boks
1048 Blindern
0316 Oslo 3
Norway

Dr. L. Pitchford
CNRS-U.P. Sabatier C.P.A.T.
118 Rt. de Narbonne
Toulouse 31062
France

Dr. N. Reinhardt
Integrated Applied Physics
50 Thayer Road
Waltham, MA 02154
USA

Dr. M.J. Rhee
Laboratory for Plasma Research
Univ. of Maryland
College Park, MD 20742
USA

Prof. Dr. H. Schamel
Physikalisches Institut
Universität Bayreuth
D-8580 Bayreuth
F.R.G.

Dr. K. H. Schoenbach
Dept. of Elec. Engr.
Old Dominion Univ.
Norfolk, VA 23508
USA

Dr. C. Schultheiß
Institut für Kernphysik II
Postfach 36 40
d -7500 Karlsruhe 1
F.R.G.

Dr. Krauss Vogt
DODUCO GMBH
Im Altgefäll 12
D -7530 Pforzheim
F.R.G.

Prof. P.F. Williams
Dept. of Elec. Engineering
University of Nebraska
Lincoln NE 68588-0511
USA

UNIVERSITY COLLEGE OF SWANSEA
DEPARTMENT OF PHYSICS

Professor C. Grey Morgan
(Head of Department)

Professor J. Dutton

Fax: (0792) 295324
Telex: 48358 ULSWAN G

Singleton Park
Swansea SA2 8PP
Wales U.K.

Telephone: (0792) 205678

17th August 1989

Dr. Martin Gundersen
University of Southern California
Department of Electrical Engineering
SSC-420 MC 0484
Los Angeles, CA 90089-0484

Dear Martin,

I enclose the original manuscript and one copy of our paper on "The Solution of the Continuity Equations in Ionization and Plasma Growth" which I hope you will find satisfactory.

I would like to say how much I enjoyed the Workshop at Lillehammer and think that all the other participants found it equally fruitful. Many thanks for all the hard work that you put in to make the Workshop a success.

I would be grateful if you would fax me to acknowledge safe receipt of the manuscript.

Hoping to meet you again in the not too distant future.

Yours sincerely,

Tony Davies

Anthony Davies
Reader in Physics

University of Illinois
at Urbana-Champaign

Department of Electrical
and Computer Engineering
(217)244-5137

155 William L. Everitt Laboratory 217 333-
1406 West Green Street FAX (217)244-5422
Urbana, IL 61801-2991

August 29, 1989

Dr. Martin Gundersen
University of Southern California
Seaver Science Building
Los Angeles, CA 90089-0484

Dear Martin:

I congratulate you on the successful NATO Advanced Research Workshop on the Physics and Applications of High Power Hollow Cathode Glow Switches. Besides personally enjoying myself, I feel the goals of the workshop were met. The Workshop brought together the current experts in the field and provided a forum to exchange information, critique each other's work, and formulate new workplans. The most beneficial aspect of the meeting for me, and most likely the other participants as well, was the Panel and Group discussions which followed each lecture session. These discussions, which were admittedly lively at times, provided a mechanism whereby the agenda "defined itself" by quickly focusing on critical technology issues. It is often difficult to *a priori* predict these issues without the input of those currently dealing with them.

In closing, I feel that the ARW was a success in that it has already helped reshape our research emphasis towards more pressing issues. On the nontechnical side, the accomodations, services, and setting in Lillehammer (Norway) were superb and added to the success of the meeting.

Sincerely,

Mark Jay Kushner

Mark Jay Kushner
Professor

MJK:dmt

Route 110, Farmingdale, New York 11735 516-755-4400/FAX 5167554404

Weber Research Institute

Polytechnic UNIVERSITY

August 24, 1989

Professor Martin Gundersen
University of Southern California
University Park
Los Angeles, CA 90089-0484

Dear Martin:

Enclosed is my "Hollow Cathode" chapter; I know I am late but I hope I am not the last. If any changes are needed, please let me know.

I think the Workshop was a big success, very stimulating and also enjoyable. I hope the book will be too.

Sincerely,

Gerhard

Gerhard Schaefer
Professor of Electrophysics

GS:ad
Enclosure

New York City:
33‿ Jay Street
Brooklyn, NY 11201
718-260-3600
FAX 7182603136

Long Island:
Route 110
Farmingdale, NY 11735
516-755-4400
FAX 5167554404

Westchester:
36 Saw Mill River Road
Hawthorne, NY 10532
914-347-6940
FAX 9143476939

The Physics and Applications
of High Power Hollow Electrode Glow Switches

NATO

Advanced Research Workshop

Lillehammer, Norway
July 17 - 21, 1989

Abstracts

DEVICES AND RELATED PROPERTIES

Properties of the Pseudo Spark Discharge

J. Christiansen
University of Erlangen - Nürnberg
Erlangen
West Germany

Abstract

The pseudo spark is a special gas discharge, which appears at low pressures in a certain kind of hollow cathode geometry. The discharge is starting with the Townsend mechanism which is followed by a rather high charge carrier multiplication.

The pseudo spark is roughly characterized by three different steps:

1. a high resistive, long lasting (~ µs) ignition phase, which can be influenced by different trigger methods
2. a rather quick (~ 20 ns) current rise phase with exponential decreasing resistance, during which an intense electron beam can be extracted at the anode
3. a low resistive, high current, main discharge, which shows a Z-pinch like behaviour and depends on the external circuit

These properties favour the use of the pseudo spark as a fast, high current switch,which can be external triggered with a temporal jitter in the ns-regime. The features of the pseudo spark as a fast switch will be presented within the lecture.

The main characteristics of the switch are:

- a maximum operating voltage of 40 kV (one-gap-system)
- a maximum current of ~ 100 kA
- a high current rise rate of $\leq 7.10^{11}$ A/s
- the conducting plasma can be quenched during the zero current phase of an oscillating circuit, especially when long current wave forms (~ ms) are used.

The lifetime of the pseudo spark switch is determined by the erosion of electrode material in the region of the central bore hole. Corresponding investigations will be discussed.

Review of Superdense Glow Discharge

Dr. Klaus Frank
University of Erlangen
Erwin - Rommel - Str. 1
8520 Erlangen
West Germany

Abstract

The superdense glow, a diffuse, high - current density low pressure gas discharge, has found application as the conduction mechanism in ultra - high current closing switches, especially in the Russian research into pulsed power generation.

A characterization of the superdense glow will be given, in comparison to the well - known normal and abnormal glow discharge, vacuum arcs, and the low-pressure high - voltage glow discharge, respectively.

The main fields of application of the superdense glow are the repetitive switching of high voltage, high current pulses, and as an intense source of charged particles. The increasing interest in repetitive ultra - high power switching imposes constraints on the switching elements which cannot be fulfilled by state - of - the - art switches in a variety of applications. A critical assessment of the superdense glow is made, especially in terms of the most critical switch parameters like:

--limitations in peak current and rate of current rise
--triggering properties
--electrode lifetime
--maximum pulse repetition rate
--maximum pulse duration
--influence of the type of working gas .

Experimental results achieved up to now will be used to try an extrapolation of todays high - power low pressure switches towards higher peak power, higher energy per pulse, and the maximum repetition rate of high energy, long pulse duration switching.

EXPERIMENTAL REVIEW

Session Chair: K. Frank

Basic Mechanisms Contributing to the Hollow Cathode Effect

Gerhard Schaefer
Weber Research Institute
Polytechnic University
Farmingdale, NY 11735, USA

Karl Heinz Schoenbach
Dept. Electrical Engineering
Old Dominion University
Norfolk, VA 23508, USA

Abstract

If a glow discharge is operated with a cold cathode with a slit or cylindrical hole, under certain operating conditions, the negative glow will concentrate inside the cathode with a much higher emission intensity and the discharge is called Hollow Cathode Discharge (HCD). At a constant voltage the current can be orders of magnitude higher or, at a constant current, the cathode fall voltage can be significantly lower than for a regular glow discharge. Hollow cathode discharges have, therefore, been widely used as plasma sources for atomic spectroscopy, lasers, and many other applications.

Several mechanisms have been considered to account for the specific properties of a HCD such as: pendel electrons in the hollow structure increasing the ionization rate in a smaller volume, a lower charge transfer collision probability and therefore, a higher mean energy of the ions bombarding the cathode, a higher efficiency in using neutrals (metastables and photons) for the secondary electron emission, and a higher plasma density increasing the probability of multistep processes. Recently, hollow cathode discharge switches have been operated with much higher current densities with thermal emission inside the hollow cathode. However, it is believed that the Hollow Cathode Effect still dominates the initiation phase of these discharges.

This paper will review the specific properties of HCD's and will discuss the basic mechanisms contributing to the hollow cathode effect including the influence of a magnetic field. We will also discuss pulsed HCD breakdown and the space-time dependent development of the negative glow inside the hollow cathode. A prospect of future applications will be presented.

Cathode-Related Processes in High Current Density, Low Pressure Glow Discharges

Dr. Werner Hartmann
University of Erlangen
Erwin - Rommel - Str. 1
8520 Erlangen
West Germany

Abstract

In transient high current, low pressure glow discharges, current densities of over 104 A/cm^2 have been reported, with cathode - plasma interaction cross sections of the order of ~ cm^2. The mechanism of this extraordinary high cathode emission from an initially cold metal surface is not well established up to now. The different processes for secondary electron emission and their role in the discharge mechanism are discussed. An explanation for the high cathode emission, based upon a detailed analysis of the cathode - related processes at the cathode surface, will be given which qualitatively explains the experimental results. Field - enhanced thermionic emission from a thin hot surface layer seems to be the most essential emission process. Heating of a thin layer at the cathode surface is thought to be accomplished by ion bombardment due to ions accelerated in the cathode fall. The thermal desorption of the adsorbed gas layer at the cathode surface seems to be necessary for the conduction of long duration, high current density pulses in the superdense glow mode.

Comparison of Electrode Effects in High Pressure and Low Pressure Gas Discharges like Spark-Gap and Pseudo-Spark Switch

J. Christiansen, W. Hartmann, C. Kozlik
Univ. of Erlangen, FRG
and
W. Krauss-Vogt, R. Michal
DODUCO GmbH Pforzheim
FRG

Abstract

The mechanisms of the interaction between plasma and electrode material in a pseudo-spark-discharge seem to be of fundamental interest . Therefore, molybdenum electrodes, stressed by long term operation in a PFS as well as in a spark gap test device were studied with a scanning electron microscope. In addition, electrodes with a 10 μm molybdenum coating deposited by a PVD-process were also applied, both in the PFS and in a spark-gap configuration. In this contribution observations about the influence of the pseudo-spark discharge plasma on the electrode surface are reported. By comparing the results with the effects caused by a high pressure spark discharge, conclusions concerning the discharge mechanism can be drawn.

EXPERIMENTAL STUDIES

Session Chair: P. F. Williams

Mapping and Modelling of the Cathode Fall and Negative Glow Regions

J. E. Lawler*, E. A. Den Hartog*, W. N. G. Hitchon‡,
T. R. O'Brian*, and T. J. Sommerer*.
*Department of Physics
‡Department of Electrical and Computer Engineering
University of Wisconsin
Madison, WI 53706
USA

Abstract

Experimental and theoretical work on the cathode region of a cold-cathode helium glow discharge is described. A current balance, or ratio of ion to electron current, at the cathode is deduced from precise electric field maps and gas density measurements for five discharge current densities. Monte Carlo simulations are compared to the empirical current balance for the five cases. New discharge diagnostics based on LIF are described and are used to determine the density and temperature of the low energy electrons trapped in the negative glow. The Convective Schema is described and used for a self-consistent (electric field) kinetic model of the cathode fall region. Prospects are good for self-consistent kinetic models from electrode-to-electrode based on the Connective Scheme.

Emission Spectroscopy in Optically Thick Gas Discharges

D . Karabourniotis
Physics Department
University of Crete
714 09 Iraklion
Crete, Greece

Abstract

Emission-line spectroscopy can be used for plasma diagnostics, i.e., for the determination of the plasma temperature, the plasma structure and the distribution of populations among the energy levels.

Optically thin lines emitted by an axisymmetric discharge plasma allow the determination of the population density of the upper level of the line-producing transitions. Then, assuming LTE, application of the equilibrium laws allows the evaluation of the plasma parameters.

In optically thick gas discharges where plasma inhomogeneity and self-absorption of the radiation are present, the spectral line shapes undergo considerable self-reversal. In this case, conventional spectroscopic methods based on optically thin lines are impracticable.

The shape of a self-reversed line may contain copious information on the processes accompanying the discharge. In order to use self-reversed lines for diagnostic purposes it is necessary to approximate the complex plasma state by simplified models. In particular, the Bartels and Cowan-Dieke models for line self absorption have found many applications for the study of optically thick plasmas in LTE state. Particular attention is paid here to recent extensions of the Cowan-Dieke model and on the applicability of this model in the study of the population density of excited states in an arc without the LTE assumption. Experimental results and their interpretation concerning the relative populations of Hg in arcs used as light sources will be discussed briefly .

An Analysis of the High Current Glow Discharge Operation of the BLT Switch

G. Kirkman and M. A. Gundersen
University of Southern California
Department of Electrical Engineering
Los Angeles, California 90089-0484

Abstract

Recent experimental studies of the Back Lighted Thyratron switch are to be reported. The optically triggered switch has operated at voltages >30kV and currents >80kA. Streak camera observations at 10kA show that the discharge is a homogeneous diffuse glow like discharge with a cross sectional area of $1cm^2$. Spectroscopic measurements of the discharge plasma estimate the electron density and temperature to be 10^{15} cm^{-3} and <1eV respectively. The discharge plasma observed in both the electrode gap and electrode backspace will be described along with a discussion of the conduction and cathode emission processes.

This work was supported by AFOSR and ARO

GENERAL DIAGNOSTICS

Session Chair: J. E. Lawler

Measurements in a Magnetically Confined Plasma

J.B. Almeida and F. Guimaraes
University of Minho
Braga, Portugal

Abstract

We detail our latest findings on argon plasmas created by plannar magnitron sputtering sources, using electroslatie probes and emission spectroscopy.

Laser-Induced Fluorescence Measurements of Number Densities of Ionized and Neutral Metal Atoms

Gunter Lins
Siemens AG, ZFE F1 TPH 32
P.O.B. 32 20, P-8520 Erlangen
West Germany

Abstract

Laser induced fluorescence offers itself as a useful tool to study the role of metal vapor during pseudo spark discharges and in the recovery of pseudo spark switches. We report our experiences with the application of LIF to the measurement of atomic and ionic number densities during and after vacuum arcs which were undertaken to investigate the influence of these species on the switching properties of vacuum circuit breakers.

In the presence of a plasma, the process of LIF is strongly disturbed by collisional depopulation of the upper fluorescence level. In the case of copper, this results in sensitized fluorescence from the $4^2P_{1/2}$ level which is closely coupled by collisions to the optically pamped $4_2P_{3/2}$ level. The ratio of sensitized to line fluorescence is a measure of the collisional interaction, which has to be taken into account in evaluating the fluorescence data. It can be shown experimentally that after extinction of the arc, the perturbation by collisions ceases sufficiently fast to allow LIF measurements of neutral and charged atoms.

Such measurements were performed for neutral copper, chromium, and tungsten, and for singly ionized tungsten. Atomic and ionic densities between $10^{14}m^{-3}$ and $lO^{19}m^{-3}$ were observed with local resolution of the order of 1 mm3 . The fast decay of the ion density: (~ 3 orders of magnitude within 15 /us) after extinction of the arc can be well correlated to the recovery of the switch gap.

Similar measurements are being prepared for pseudo spark discharges.

Streamers of Atmospheric N_2: New Empirical Results

P.F. Williams and F.E. Peterkin
Department of Electrical Engineering
University of Nebraska-Lincoln
Lincoln, NE 68588-0511
U.S.A.

Abstract

We have obtained streak and high speed shutter photographs of streamers in a trigatron spark gap filled with N_2 at roughly atmospheric pressure. The streamers are initiated in the high field region surrounding the trigger pin, and propagate across the main gap. We have observed streamers for main gap charging voltages ranging from roughly 50% to 99% of V_{SB} (the static self-breakdown voltage of the gap), and for both charging polarities, producing cathode- and anode-directed streamers. Streak photography allows us to measure the propagation velocity of the streamers. We find that they propagate with a nonconstant velocity which, for charging voltage near VSB, ranges from $\approx 2 \times 10^8$ cm/sec initially to more than 10^9 cm/sec. High speed shutter photography shows the shape of the streamers. For charging voltage near V_{SB} cathode -directed streamers are well defined, and have a diameter of ≈ 2 mm. Anode-directed streamers, on the other hand, are somewhat thinner, and have a more featherlike appearance. For lower charging voltages, the cathode-directed streamers remain well-defined, whereas the anode-directed streamers become more and more like an electron avalanche drifting across the gap. We also observe a jump in the main gap current when the streamer approaches the distant main gap electrode. From the magnitude of this jump and the streamer body diameter determined from the shutter photographs, we can measure the free electron density in the streamer. We find densities in the range 10^{14} - 10^{15} cm^{-3}.

THEORETICAL MODELING

Session Chair: M. J. Kushner

Computer Modelling of Ionization and Plasma Growth

A. J. Davies and W. Niessen
Department of Physics,
University College of Swansea
Singleton Park
Swansea, SA2 7BT,
Great Britain

Abstract

In the study of the operation of hollow-cathode devices, such as the pseudospark switch, the development of successful numerical models of the growth and switching mechanisms would greatly help the design and development of reliable devices.

During the last few years there have been considerable advances in the numerical algorithms available for simulating the spatial and temporal growth of the initiatory plasma in the hollow cathode and in the high-field inter-electrode regions.

In the hollow-cathode the discharge may be modelled by solving the hyperbolic continuity equations which govern the plasma development taking into account the space-charge distortion of the applied field by the growing plasma. In this procedure, great care must be taken to use efficient and stable methods for the integration process and a review will be made of the different techniques that are now available. It is also important to use a fast and accurate method for computing the field distributions during the growth and, again, the alternative methods will be described and compared.

Outside the hollow-cathode non-equilibrium effects dominate and the discharge growth must be studied using Monte-Carlo or Boltzmann techniques. The interface region at the entrance to the hollow-cathode is particularly difficult to treat and possible ways of modelling the growth in this region will be discussed.

Scaling Parameters for Optically Triggered Hollow Cathode Switches Obtained by Computer Simulation

Hoyoung Pak and Mark J. Kushner
University of Illinois
Department of Electrical and Computer Engineering
Urbana, Illinois 61801
USA

Abstract

The performance of hollow cathode plasma switches depends critically on physical and geometrical parameters such as cathode radius, electrode spacing, and trigger mechanism. In order to investigate these dependencies and obtain scaling laws for optically triggered psuedospark switches, a computer simulation has been developed. The model is a multidimensional "beam-bulk" representation of the switch which has been used to parameterize performance as a function of geometry and method of switching. Results will be discussed in which we compare symmetric vs non-symmetric designs, and the beam like behavior of the plasma.

The Onset of the Pseudospark
- Numerical Simulation of Prebreakdown in a Hollow Cathode Geometry -

K.Mittag
Kernforschungszentrum Karlsruhe, IDT
Postfach 3640
D-7500 Karlsruhe
Federal Republic of Germany

Abstract

One most exciting feature of a pseudospark discharge is the appearance of a high current density, well focussed electron beam. Numerical simulations of the prebreakdown in the hollow cathode region of a pseudospark diode give the clue to the understanding of this phenomenon.

The theoretical model is based on a fluid description. The motion of electrons and positive ions are followed in space and in time by solving simultaneously their continuity equations an Poisson's equation in a two-dimensional rotational symmetric geometry.

During a build-up phase a large charge carrier multiplication occurs in the hollow cathode region. It is due to primary ionization by electrons, secondary electrons from the walls originating both from photoeffect and impinging positive ions, and from positive ions entering from the anode-cathode region. The electrons are extracted quickly out of the hollow cathode region by the electric field of the diode gap. As a result a positive space charge builds up which has its maximum on axis in the hole region.

It follows an ignition phase during which the positive space charge starts to enhance the applied electric field in the hollow cathode region near to the hole. Then the charge carrier densities grow overexponentially because electrons are quickly attracted by this positive

charge, and ionizitation also is enhanced.

Consequently, an electron beam of high current density and very small diameter is ejected from the hollow cathode into the anode-cathode region. These theoretical predictions agree well with corresponding experimental results.

Self-Consistent Discharge Modeling

J. P. Boeuf
Centre de Physique Atomique de Toulouse (CNRS URA 277)
Université Paul Sabatier
118 Route de Narbonne
31062 Toulouse Cedex
France

Abstract

Self-consistent numerical models of DC and transient glow discharges are presented. These models are based on the solution of fluid equations describing the transport of charged particles, coupled with Poisson's equation for the electric field.

In the first part of this lecture, the assumptions implied by the fluid description of the electron and ion kinetics will be discussed. A realistic and simple way to describe the electron kinetics in the cathode region of a glow discharge consists in considering two electron groups: the first group corresponds to high energy electrons accelerated through the sheath and the second group represents low energy electrons which form the bulk of the distribution.

The numerical models will be briefly described in the second part. Very efficient and stable implicit numerical techniques have been developed: these techniques are similar to those which are extensively used in the field of semiconductor device modeling.

Examples of results will be presented in the third part. These include one dimensional and two dimensional models of DC glow discharges, and a study of the transient behaviour of the discharge after a perturbation (laser induced photoemission on the cathode); comparisons between numerical and experimental results will be presented (the experimental part consist in space and time resolved measurements of the electric field by LIF techniques, by J. Derouard et al. in Grenoble).

A Hybrid Approach to Non-equilibrium Electron Kinetics

E.E. Kunhardt and N. Marcuvitz
Weber Research Institute
Polytechnic University
Route 110
Farmingdale, NY 11735

Abstract

The ensembled-averaged dynamic behavior of an assembly of electrons in a background gas under the influence of a space-time varying field and in the presence of boundaries may be described at a "microscopic" level by the time-dependent distribution function, f(v, r, t) (where v is the velocity, r is the position, and t is time). Given the initial state of the assembly and the conditions at the boundary, the distribution function at any other time may be obtained from the kinetic equation that describes the evolution of f.

In the presence of boundaries and/or for time scales in the order of a collision time, it is convenient to divide the distribution function into two parts:

$$f(\vec{v}, \vec{r}, t) = f_M(\vec{v}, n(\vec{r}, t), \bar{\varepsilon}(\vec{r}, t), \vec{u}(\vec{r}, t)) + f_a(\vec{v}, \vec{r}, t)$$

f_M is a momentum dependent function with macroscopic space-time scales, whose equation of evolution is equivalent to the Boltzmann transport equation. The equations for the evaluation of the first three moments, density n(r,t), average velocity u(t,r), and mean energy ε(r,t) and the corresponding macro-kinetic equation form a closed system. In this case, f_M is valid for time scales greater than V_m^{-1}, the momentum exchange time. f_a is a fast varying part necessary to satisfy initial/boundary conditions and is represented in terms of localized functions in velocity space. With this representation, characteristic times can be associated with regions of v-space, and the dynamics of each region elucidated . The coupling matrix between different regions of v-space can be obtained in a semi-analytical manner.

The evolution of f in terms of f_M and f_a will be discussed.

Double Layers

Prof. Dr. H. Schamel
Physikalisches Institut
Universität Bayreuth
Universitätsstraße
D-8580 Bayreuth
Federal Republic of Germany

Abstract

The presentstatus of double layers that are narrow monotonic transitions of the electrostatic potential and occur in the volume of voltage- and current- driven plasmas is reviewed.

A Self-Consistent Model of DC Glow Discharges with Abnormal Cathode Fall

Karl H. Schoenbach, G. Gerdin, L. Vahala, and Hao Chen
Physical Electronics Research Institute
Old Dominion University, Norfolk, VA
and
G. Schaefer
Weber Research Institute
Polytechnic University, Farmingdale, New York

Abstract

A self-consistent model for an abnormal gas discharge, including the nonequilibrium region of the cathode fall, was developed. It combines microscopic particle simulation by means of Monte-Carlo methods with a fluid model of the gas discharge. The model permits the calculation of the steady state electrical field distribution, the charged particle densities and the current densities in the positive column and the cathode fall of a high current glow discharge. The model was used to simulate a linear glow discharge in a mixture of He and SF_6 with a current density of 1 A/cm^2. The computer discharge voltage agrees well with measured values. The application of this model to hollow glow discharges will be discussed.

Work supported by NSF and by SDIO/IST under management of ONR.

Modeling of the discharge plasma in a back lighted thyratron during the conduction phase

H. Bauer, G. Kirkman and M. A. Gundersen
Department of Electrical Engineering-Electrophysics
University of Southern California
Los Angeles, California 90089-0484
USA

Abstract

Temperature, energy, and densities of two electron components, i.e., isoptropic "bulk" and anisotropic beam electrons, are evaluated for a Back Lighted Thyratron (BLT) switch plasma. Measured plasma parameters are peak electron density of $1\text{-}3\times10^{15}$ cm^{-3} and peak current density of 10^4 A/cm^2. Estimates of a very small cathode fall width during the conduction phase and high electric field strengths lead to injection of an electron beam with energies $\varepsilon \geq 100$ eV and density of $10^{13}\text{-}10^{14}$ cm^{-3} into a Maxwellian "bulk" plasma. From a Fokker-Planck equation it was found that those electrons can penetrate the typically 3mm long "bulk" plasma channel in the gap before they become thermalized. Collisional and radiative processes of monoenergetic beam electrons, "bulk" plasma electrons and ions, and atomic hydrogen are modeled by a set of rate equations and line intensity ratios are compared with measurements. For an initial density $n_{H2}=10^{16}$ cm^{-3} the evaluated

"bulk" plasma parameters are electron density of $1\text{-}3\times10^{15}$ cm^{-3} and electron temperature of 0.8-1 eV. Time dependent calculations of the rate equations during the conduction and recovery phase including heat losses and recombination near the insulator walls are in progress and results will be presented.

Electron Rate Coefficients at Very High E/n

L.C. Pitchford
Centre de Physique Atomique
URA 277 (CNRS)
31062 Toulouse
France

Abstract

A simple, multi-beam model has been developed to describe the electron impact ionization and excitation rate coefficients at very high values of E/n. We are primarily interested in the range of E/n for which any individual electron can gain energy without limit in the electric field because of the decreasing importance of collisions as energy and momentum loss processes for electron energies past several hundred electron volts. In spite of this tendency of individual electrons to runaway, averages over the ensemble of the electron swarm; i.e., the electron average energy, drift velocity, and rate coefficients, are well-behaved because of the production of secondary electrons in the ionization process. Comparison with the recent experiments of Hays, et al in nitrogen and hydrogen for E/n up to and beyond 10,000 Td (10^{13} V cm^2) will be presented as well as with our recent Monte Carlo calculations. An evaluation of the various computational assumptions (such as isotropic or forward electron-neutral scattering) will also be described.

NEW APPLICATIONS

Session Chair: P. Choi

Electron Beam Properties of the Pseudospark Discharge

P. Choi
The Blackett Laboratory
Imperial College of Science Technology and Medicine
London SW7 2BZ
United Kingdom

Abstract

Experiments have shown that electron beams of different properties are produced in the pseudospark discharge both before and after the gas breakdown. Two different regimes of prebreakdown electron beams can be identified; a low current high energy beam and a relatively high current beam of low energy. The high energy beam is related to the hollow cathode geometry and is found to be present even in the absence of subsequent gas breakdown while the lower energy beam is always associated with voltage breakdown. After breakdown, low energy electron beams up to a significant fraction of the discharge current are observed. The present paper will describe various experimental measurements and discuss the mechanisms of electron beam generation in the different regimes.

New Applications for Pseudosparks and BLT Properties

M. A. Gundersen
University of Southern California
Los Angeles CA 90089-0484
USA

Abstract

This talk wiill discuss the application of the pseudospark-type device to the development of practical plasma based devices to be used to test and develop concepts for plasma based accelerators, electromagnetic sources, and related devices such as plasma lenses. Although there has been considerable simulation effort, there are very few practical devices, and the realization of such devices is one of the most important limitations in further development. Using the pseudospark, a uniform high density plasma source has been developed at USC, and a very high density cathode has been demonstrated. Applications of these results include electron beam devices, accelerators, and electromagnetic wave sources; development of high density, uniform, low temperature plasmas for these applications, study of limitations in length and density, and development of practical models of the physical processes responsible for the plasma behavior, using sophisticated experimental investigations and theoretical models. The objects of the new applications are thus to seed development of new concepts including plasma loaded accelerators, free electron lasers, free electron lasers with plasma loading, and various millimeter and micrometer wave devices, and to facilitate the implementation of new plasma based technology by providing a basic understanding of physical processes and producing a new generation of plasma based devices that are based on new concepts.

Emittance Measurement of a Pseudospark Produced Electron Beam

M.J. Rhee and E. Boggasch
Laboratory for Plasma Research
University of Maryland
College Park, Maryland 20742, U.S.A.

Abstract

We report the first measurement of the rms emittance of a pseudospark produced electron beam. A 6 gap pseudospark chamber with argon gas was operated at ~25 kV and produced a ~10 Hz repetitive pulse train of electron beams. Typically, a beam of average energy 20 keV, peak current ~50 A and pulse duration ~10 ns FWHM was extracted from the chamber. The rms emittance was evaluated by using the split-pinhole method; distributions of sheet beamlets formed after passing through a series of thin slits were recorded on a radiachromic film and were analyzed for the emittance. A typical value of rms emittance was found to be $\varepsilon = 4[\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2]^{1/2} = \sim 55$ mm-mrad, yielding a normalized emittance of $\varepsilon_n = \sim 15$ mm-mrad. The normalized brightness of the beam was then estimated as $B_n = I/\varepsilon_n^2 = \sim 2 \times 10^{11}$ A/(m^{2}rad^2), which appears to hold a promise for the pseudospark as a high brightness electron beam source.

New Ways of Electron Emission for Power Switching and Electron Beam Generation

H. Riege
CERN PS-Division
CH-1211 Geneva 23
Switzerland

Abstract

Strong electron emission from plasmas or solid surfaces is the basis of many applications such as high-power switching or intense electron beam generation. The electron emission in pseudospark geometries from the interior of the hollow cathode and from the outer cathode surface is discussed. The emission is compared with other emission methods by taking electron current densities, spatial and energy distributions, and control mechanisms into account. A combination of different types of emitters may be the best solution to efficient power switching and intense electron beam production. As examples ferroelectric emitters in pseudospark - like switches and electron beam sources are described.

Sub-Microsecond Pulsed Power Supplies for Electrostatic Treatment of Flue Gas

Ivo Gallimberti
Department of Electrical Engineering
University of Padova
Italy

Abstract

In the frame of the "Project for Environment Protection", ENEL, the Italian Utility for electric energy production, is developing innovative technologies to reduce the pollutant emissions from thermoelectric power plants. The most promising of these technologies is based on the use of corona discharges to induce both the precipitation of fly ash and the reduction of Nitrogen and Sulphur oxides.

In this paper these techniques are briefly described, together with the results of the protype plants, and the possible future applications on industrial scale are discussed.

The design of the pulsed power supplies for the energization of the plants is the crucial point for practical applications of these technology. The technical specifications of the power supply are the following: load capacitance >10 nF, power on the load >100 kW, impulse voltage 200 kV, rise time <100 ns, overall duration 1 us, peak current >10000 A, repetition frequency 300 Hz, efficiency >80%. The pulse voltage is obtained by discharging a capacitor into the load via an oscillating circuit, dumped by the corona discharge itself: the switching element has been actually realized with a triggered spark-gap in pressurized flowing gas. The requirements of this switching element are discussed, together with the possible application of hollow cathode glow switches.